

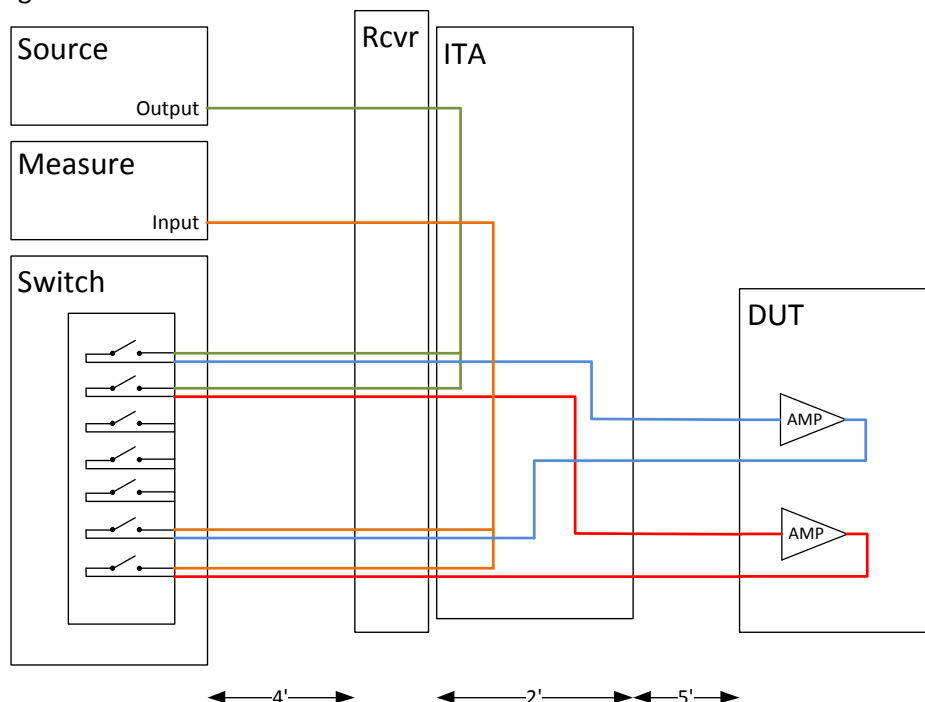
Improved Switching Architectures for ATE Systems

by Robert Waldeck

Application Note

Good test system designs don't just happen, they are carefully planned. All too often test systems get designed by committee. First the test engineers get together and pick their favorite instruments. The better ones will even look at the test requirements to see what is really needed before diving into the instrument selections. Frequently, they visit the product designer, and copy what's on his bench. The one element I have never seen on a development bench is a switching system, and typically at some point in the test system design phase, someone will say, "oh yeah, let's throw in some switches" at which point a couple of general purpose switch cards are selected because no one is really sure exactly how they are going to be used or what selection criteria are important. Once all of the instruments and switches get selected, everything is cabled directly to the interface, because it's easy, and you can buy pre-made cables to do that, and then the Interface Test Adapter or ITA design process begins.

So, the test engineer sits down, and says "well, all of these instruments on the left need to get connected in various combinations to all of those Device Under Test (DUT) pins on the right, so let's start drawing lines." Before you know it, you have a system design like the one below. All of the dots have been connected, and the engineer starts writing the test program while the technicians start building all of the hardware.



Having been in this business my entire career, I can tell you this happens quite often. So what's good and bad about this system design?

The good – The test engineers wisely decided to use a test receiver which provides a number of benefits, like being able to test multiple DUT's on the system simply by changing the ITA. The receiver also provides the ability to create a Self-Test adapter or shorting plug allowing the creation of a self-test program. They have also designed a set of cables to connect the DUT to the ITA, and this will allow them to place the DUT on a bench or in a test chamber if necessary.

The bad – There are a few problems with this design. Because a simple general purpose switch was selected, there are a number of round trips to the switch card increasing both the path length, and leaving behind some very nasty stubs well over four feet long. This has the effect of reducing bandwidth, while increasing Insertion loss. Not to mention added crosstalk, and noise pickup, depending on how well shielded these paths are. I calculate about 21' of wire from the source instrument to the input of the amplifier in the DUT with a 4' stub sticking out of the middle. I have seen designs involving numerous round trips to the switch cards, resulting in more than 50' of wire length. Assuming the proper wire types were used, and if the switch card supported the specific type of shielded wire selected, one might end up with a reasonable signal at the end of this 21' path, but the real killer is the stub. This 4' piece of wire hanging out of the middle of the circuit is going to either behave like a long antenna picking up radio free Europe, or if it's a shielded wire, it's going to look like a capacitor in the middle of the path. In either case, it's going to have a disastrous effect on the signal. Worst of all, is that we have gone through so much wire, and been subjected to so many additive and subtractive effects, that we no longer have any idea what the signal level into the DUT is, and this will be a real problem when it's time to measure gain.

What have we learned?

1. Path lengths should be as short as possible.
2. Conductor types need to be matched as closely as possible to the DUT, and switches must be selected to match these conductor types.
3. The switching scheme needs to create direct paths, and eliminate stubs.
4. Impedance discontinuities caused by mixing wire types along the path need to be minimized.

But what's the really important take-away?

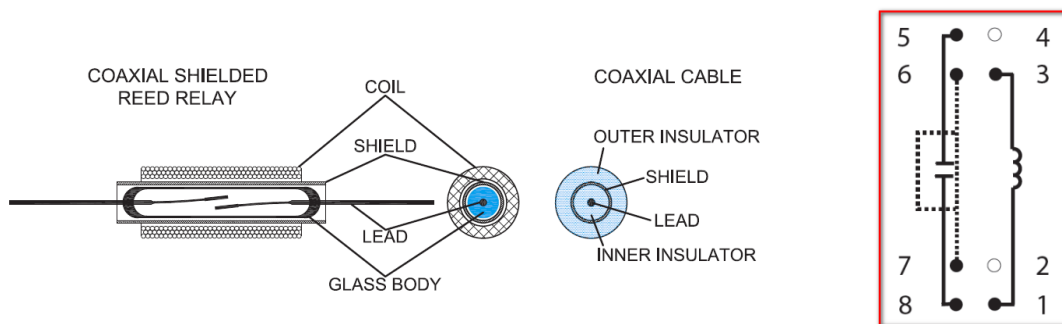
If you remember nothing else about this whitepaper, remember this one thing. The switching system becomes part of the circuit. If you have a nice balanced 50 ohm coaxial connection between the Source and the DUT, and then need to impose a switch in the middle, make sure it does as little as possible to upset the nice 50 ohm balanced circuit. Electrically, the switch card is part of the cable. The general purpose unshielded SPST switch our friends selected above was inexpensive and general purpose, but there's no way it can be imposed into the circuit without creating a big discontinuity in the middle, and breaking the nice shielded path we had before.

Now that you have a good understanding of what goes wrong during the switch design process, I would like to show you a few of Giga-tronics^{ASCOR} more interesting switch card designs, and how they were intended to be used.

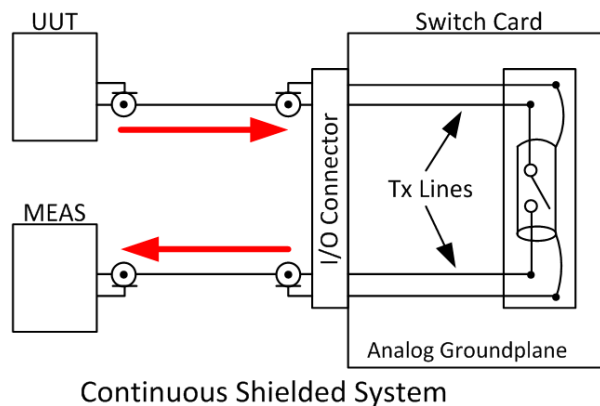


First let's look at some of the important things that make the Giga-tronics^{ASCOR} cards unique. One of the first things is our frequent use of shielded Reed Relays. Reed Relays are encapsulated in a glass tube. The manufacturer places a conductive sleeve over the glass tube, and provides connections to the sleeve at both ends. It works out that the characteristic impedance of this assembly is close to 50 ohms. The use of these relays and some good PC board design practices enables Giga-tronics^{ASCOR} to create a switch module that can be placed in the middle of a signal path with minimal disturbance to the Impedance as well as keeping the shielded path intact.

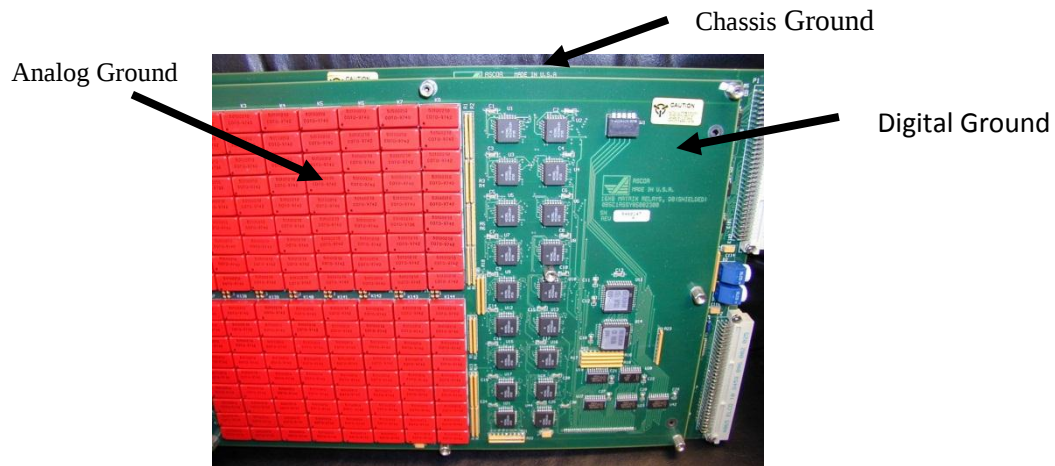
One other significant benefit of Reed Relays that is frequently overlooked is something called "Dry" switching. Most relays are rated for a specific level of voltage and current. These relays actually require this voltage and current to work properly. The small arc that occurs as the relay opens actually has a cleaning effect on the contacts. With the possible exception of power switching, which is also typically done "cold" or "dry", most ATE switching is "Dry" switching where no current is drawn. Think about it, most test programs I have seen, close all of the switches in the path before the first instrument is turned on. Because of this, the relay contacts are never "cleaned" and over time the closed resistance slowly increases. Reed Relays are hermetically sealed so they stay cleaner, and they also use a specific metal called Ruthenium on the contact surface, which provides long life, and consistent low resistance connections in "dry" switching applications. Not to mention, how does a life of 1 billion cycles sound?



Here's an example of how the switch card becomes part of the continuous path from the instrument to the DUT. The paths along the PC Board from the connector to the relays are designed like a transmission line to further eliminate impedance discontinuities.



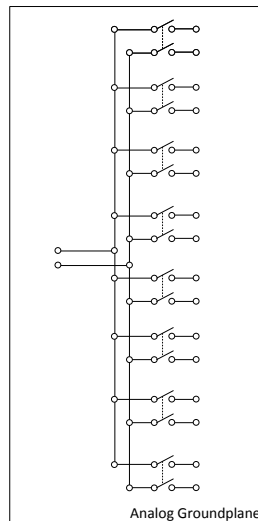
All Giga-tronics^{ASCOR} switching boards are designed with three ground planes. The first is the digital ground plane at the communications end of the board. This prevents clocks and other communications signals from coupling into your sensitive DUT signals. Many manufacturers use a single ground plane, and suffer from the effects of communication coupling into the DUT signals. We have had a number of customers come to us after having tried other manufacturers switch cards unsuccessfully. The second is the DUT analog ground plane which is a separated ground plane for the DUT portion of the board so that there is an electrically quiet ground plane where DUT grounds can be connected, and carried continuously through the switch card without picking up extraneous signals or ground loops. Finally, there is the chassis ground which is also kept separate to prevent ground noise from coupling into DUT signals.



Now that we have covered the design basics, let's look at some basic building blocks and how they are used to create a switching module.

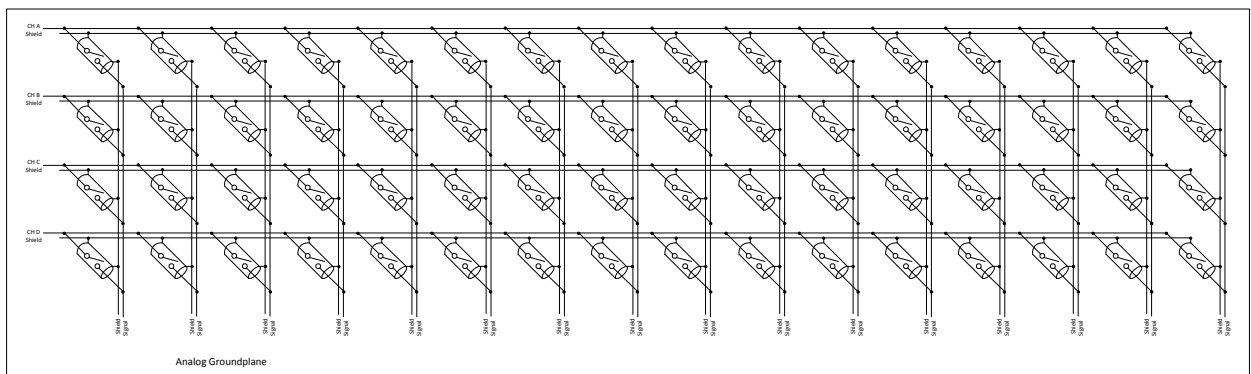
Multiplexer or Tree Switch

When you have one instrument going to many places, the MUX is the best solution. It allows you to create many direct paths to the DUT without creating any stubs. Here is a diagram of the 4208 module which has six (1x8) 2-wire unshielded multiplexers on it. This diagram is one of those (1x8) multiplexers.

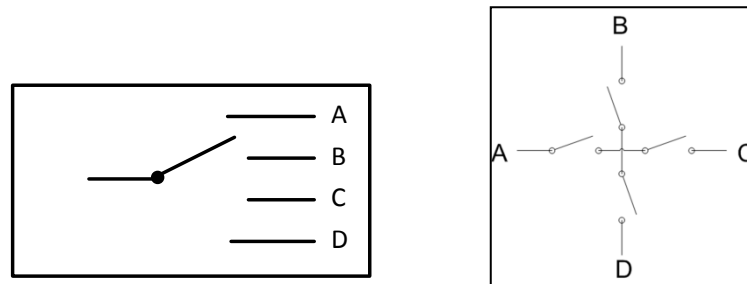


Matrix Switch

This structure allows several instruments to be connected to any of a group of DUT pins. This construct is so useful and flexible that a common first reaction is to try to use them for everything. While this sounds like a great idea, we all know there's no free lunch. Matrix switches suffer from bandwidth limitations. You can see that the matrix will always violate one of the earlier rules, in that there is always some stubbing effect from the unused channels. Although these internal stubs are kept as short as possible to improve performance, you can see that there is always a tradeoff between bandwidth and flexibility. Here is a diagram of the 4116 switching module which has a (4x16) 1-wire shielded matrix. This allows the 4 instruments connected along the left to be connected to any of the 16 DUT pins along the bottom.



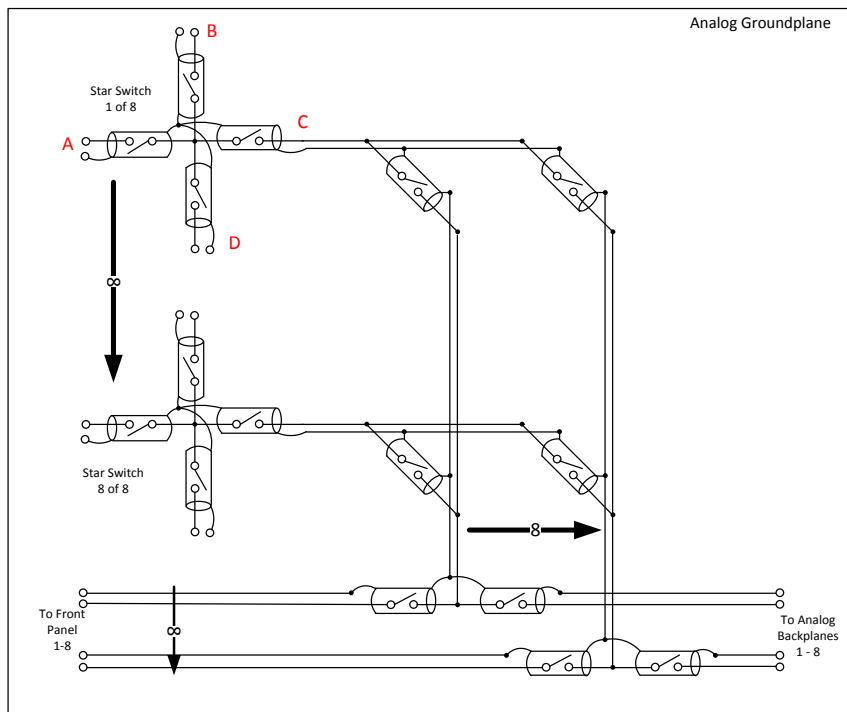
One truly unique structure which was created by Giga-tronics_{ASCOR} is the STAR switch shown on the right below. The star switch is similar to the multiplexer on the left, but without a common port. The multiplexer has the ability to connect any of the output ports to the common, but the output ports cannot be connected to one another. The STAR switch eliminates the common port completely, and allows any of the four ports to be connected to each other in any combination. The beauty of this design is that any two ports can be connected together with minimal stub effects where if a mux were used in this way, there is always a reflection from the unused common port stub.



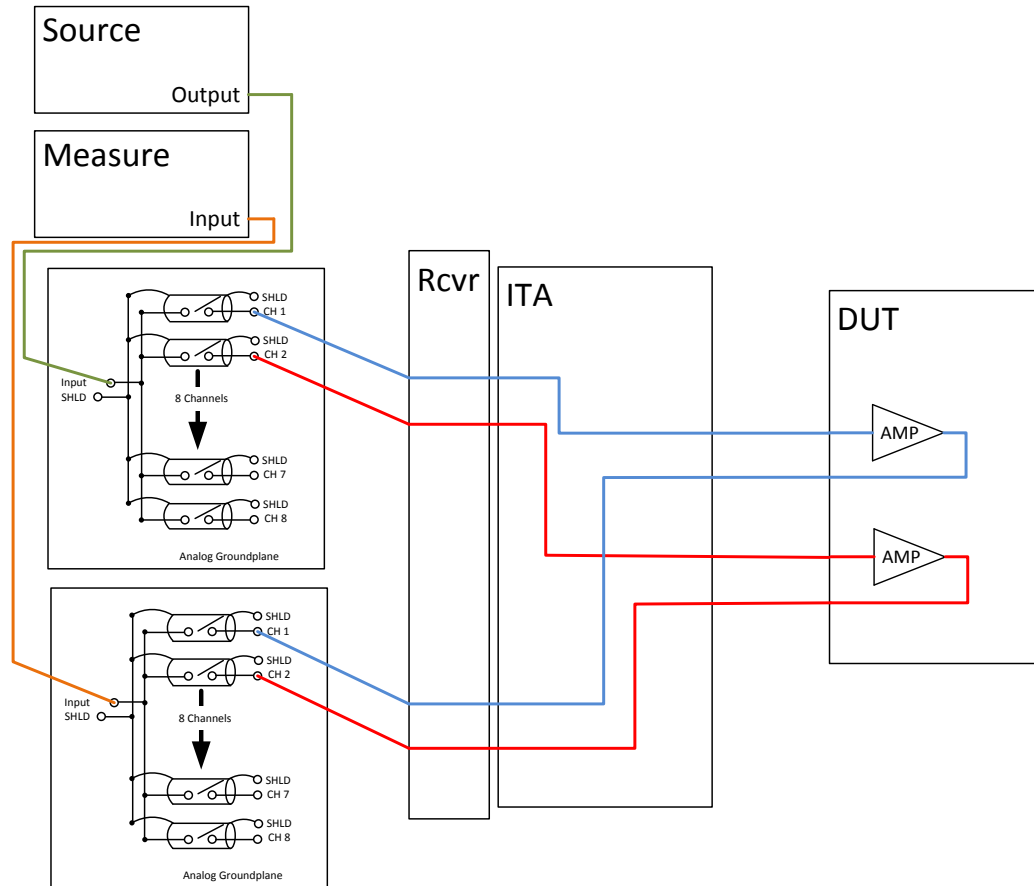
Here is a diagram of the 4513 switch module which uses a star switch, combined with a matrix. This module has an (8x8) 1-wire shielded matrix with STAR switches at one axis and backplane bus connections at the other. We will get into more detail about the bus when we start to look at applications.

Here is an illustration of the advantage of this switch. Suppose you have decided to use a matrix switch because of the increased flexibility and because you can tolerate the reduced bandwidth and stubbing inherent in its design. Then you suddenly realize you have just a few DUT ports that require a much higher bandwidth. The switch below might be able to solve your problem.

Example, the measurement instrument is connected to the STAR switch at port "B". For normal use the switch at port "C" is closed and the matrix can be used to connect to the DUT. Now, when you need a high bandwidth path, you open the relay at port "C", and use ports "A" or "D" to have a nice direct high bandwidth connection between the instrument and the DUT with virtually no stub because the matrix is disconnected. The stub length of the STAR switch is nearly insignificant.

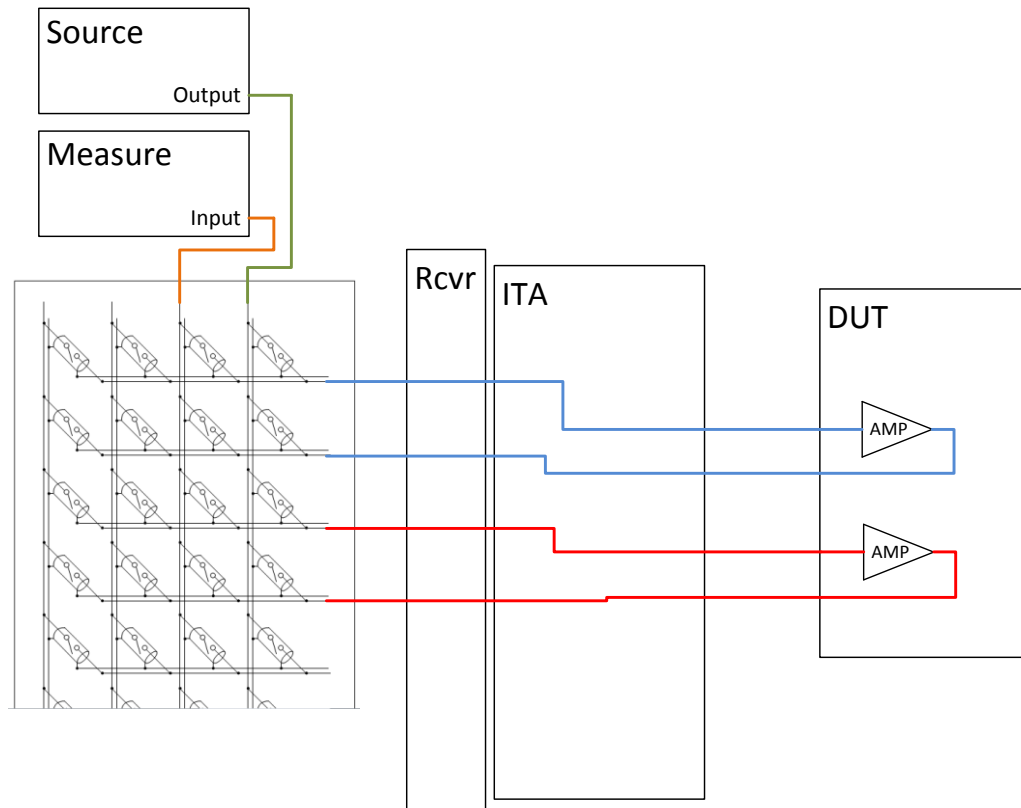


So, going back to our example test system, the question is, how would some of these switching structures be used in our example, and what benefits might we expect. The 4108 module has 12(1x8) 1-wire shielded multiplexers. Here is how two of those multiplexers might be used in our example. I've left the grounds unconnected to eliminate clutter in the diagram.



In this example the multiplexer provides a clean direct path to the DUT with no stubs connected to the path. The physical path length we had in the previous example of 21' has been reduced down to about 12'. This design provides optimal bandwidth and signal integrity. The physical path length and the insertion loss have been minimized by removing electrical round trips between the test system and the ITA. This method also provides consistent insertion loss across the multiplexer channels. One other benefit of this type of design is the ability to calibrate the instruments in place at the test interface so that signal levels are known quantities at the test Receiver.

This example illustrates how a portion of the 4116 matrix card can be applied to the example. It's obvious that the diagram of the card is cutoff and proceeds down through 16 DUT channels. It's this additional path length that forms the stub we spoke about earlier. One of the added benefits of the matrix is the ability to connect anything to anything. Unlike the multiplexer which can only connect the source instrument to the amplifier inputs, the matrix can connect either instrument to the amplifier input. There are cases where this connectivity may be required by the test plan. Path lengths have been similarly reduced as was done with the multiplexer.



As in the previous example, test signals can be calibrated at the test interface, so that the insertion loss is known at each interface pin. Cable lengths are minimized, and round trips cabling to the test Receiver are eliminated.

Analog Backplane Bus

One problem the system designer inevitably runs into in designing a switching system is that no single card ever has enough relays on it. One of the disadvantages of the traditional industry standard backplanes such as VXI and PXI is the lack of analog connectivity across the backplane. What this means is that if you want to bring an analog signal from card A to card B, you need to connect wires across the front of the cards. This is problematic for a number of reasons:

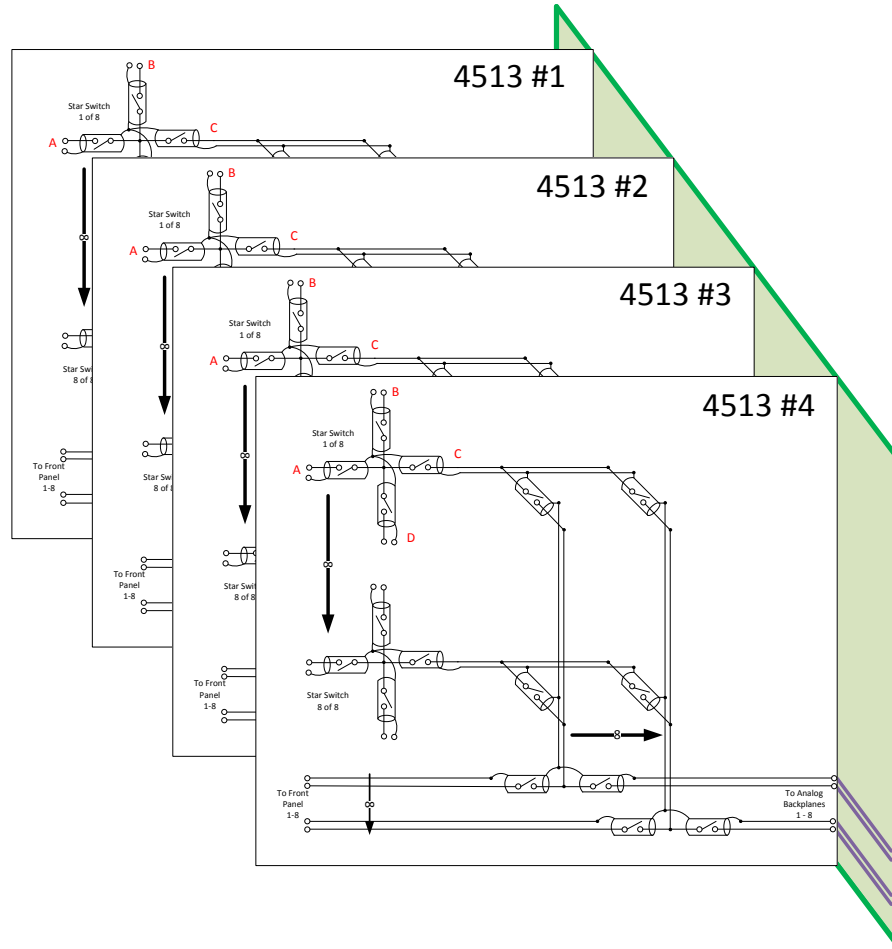
1. The connectors are also the I/O connectors to the DUT, so the multi-branched cable is born. This is particularly problematic with PXI whose small front panels cannot host multiple connectors.
2. The path length is extended, sometimes involving a change in the wire type which results in an impedance change.
3. It looks messy.
4. It breaks easily.
5. It increases the repair time by forcing you to remove the cable from several cards before a defective card can be removed. It also invariably breaks during a card replacement, so you now have a second problem.

Solution

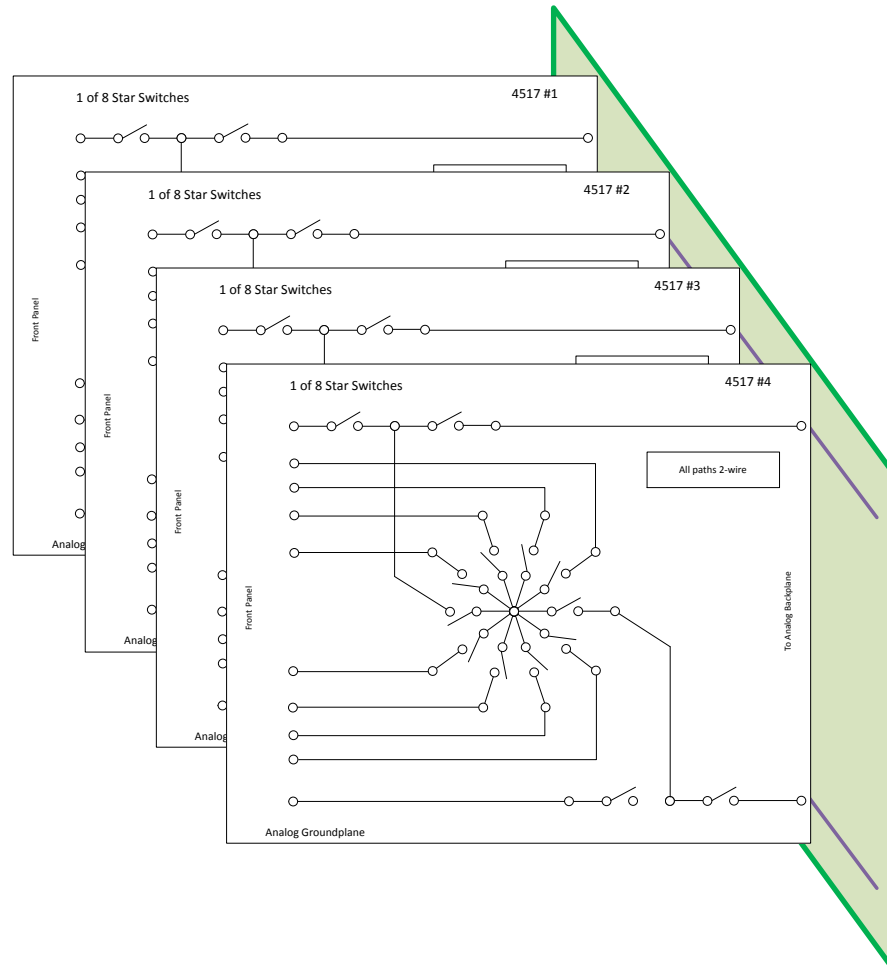
The Analog Backplane. Although Giga-tronics_{ASCOR} makes products for both PXI and VXI, we struggled with the missing Analog Backplane. Thus, the 4000 Series was born. The 4000 Series by Giga-tronics_{ASCOR} is very similar to VXI in that the cards are physically large. They are actually slightly smaller than VXI cards so that they could be installed in a VXI carrier, creating an analog backplane in a VXI chassis. These days, with LAN or GPIB controlled switching boxes being more popular, we have created a 4U eight slot chassis which has 32 channels of single ended or 16 channels of differential Analog Busses rated for 500 MHz.



Here is an example where four 4513 cards are being connected together using the Analog Backplane in the GT-8400A chassis. Connected in this way, signals can enter one card, move across the backplane, and exit another switch card.

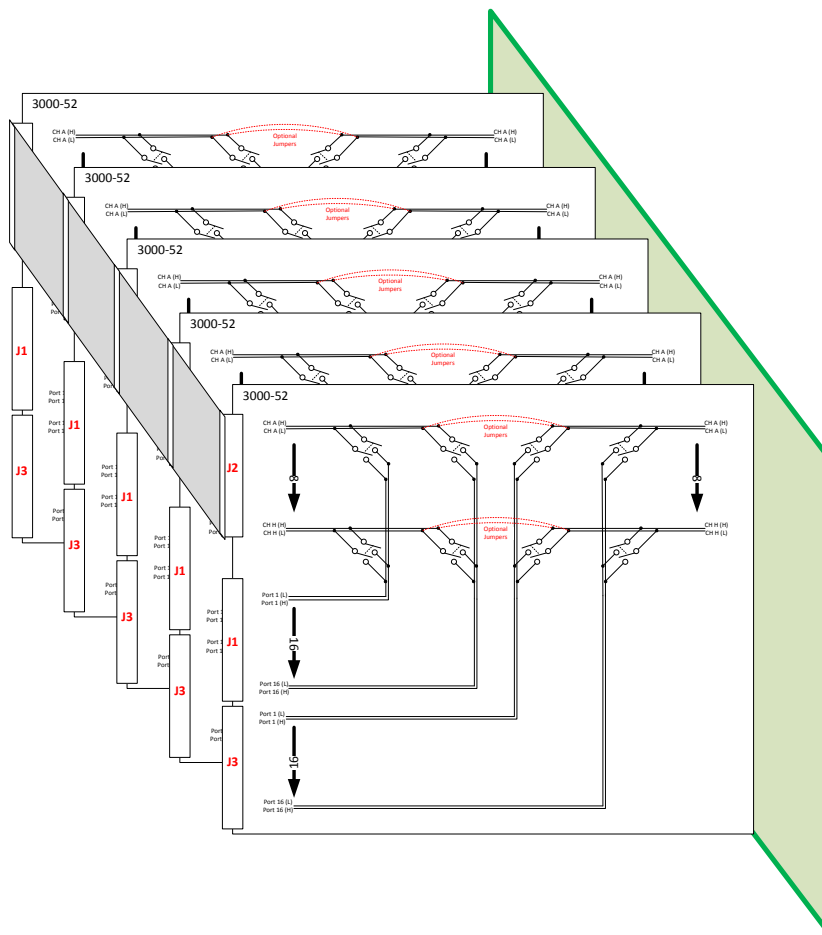


Here's another example using the 4517 switch card. This switch card has eight 10-Pole STAR switches on it, although only one is shown in the diagram. Each STAR has the ability to connect to two different busses. Using the backplane to connect the cards together in this way, the cards can be tasked as needed to support the system design. Some cards can be tasked as instrument cards to bring instrument connections onto the backplane, while other cards can be used as DUT cards to bring DUT signals onto the backplane to connect with the instruments. The real value in such a system is that the card can easily be re-tasked from one test program to the next since the relays are all software controlled.



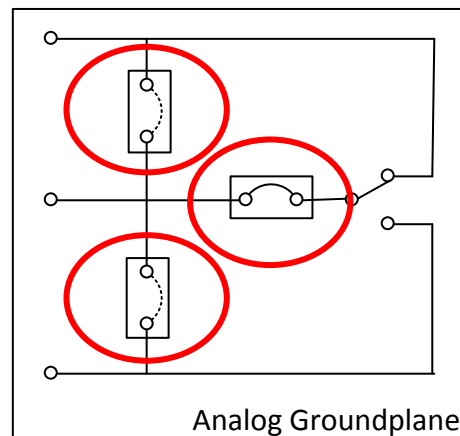
Front Panel Bus Connections

As I mentioned earlier, some of the industry standard card designs do not include the useful Analog Backplane Bus we have just been discussing. So what alternatives are provided for the VXI and PXI platforms? Some of the Giga-tronics_{ASCOR} cards have been carefully designed to allow switching fabrics to be expanded across the front of the cards using a simple ribbon cable, providing the shortest possible cable length, and a neat, easily maintainable system. Here's an example where five 3000-52 switch cards, each having a matrix of 8x32 in a 2-wire configuration has been expanded to a matrix of 8x160 pins simply by connecting them together using a ribbon cable across the J2 connectors. The J1 and J3 connectors are cabled to the test interface for connection to the DUT(s). One note of caution, expanding matrices in this way can result in a considerable loss of bandwidth. Our experts can help you with this design process.

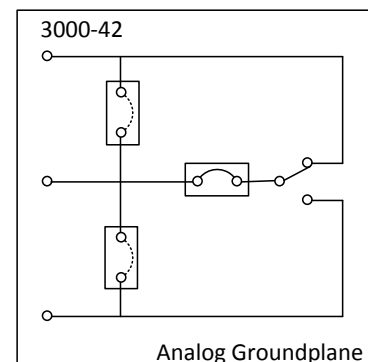
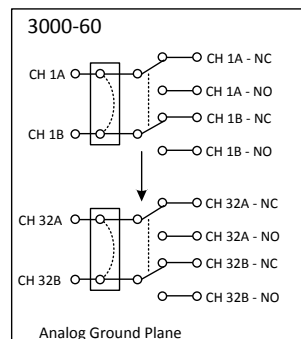
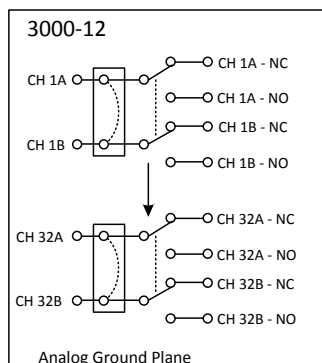


Other Unique/Useful Constructs

The 4048 card has 48 SPDT relay channels on it. Each channel is capable of 5 Amps. Ordinarily it would be difficult to get excited about a Form-C relay card, but take a close look at the typical channel diagram shown below. The items in the red circles are locations on the PC board where Thru-hole components can be mounted. These locations can also be used to install wires allowing the relay channels to be connected together to create various types of relay structures such as a multiplexer, etc. These locations can also be used to mount components such as resistors allowing the card to be used as a sort of high current programmable resistance module.



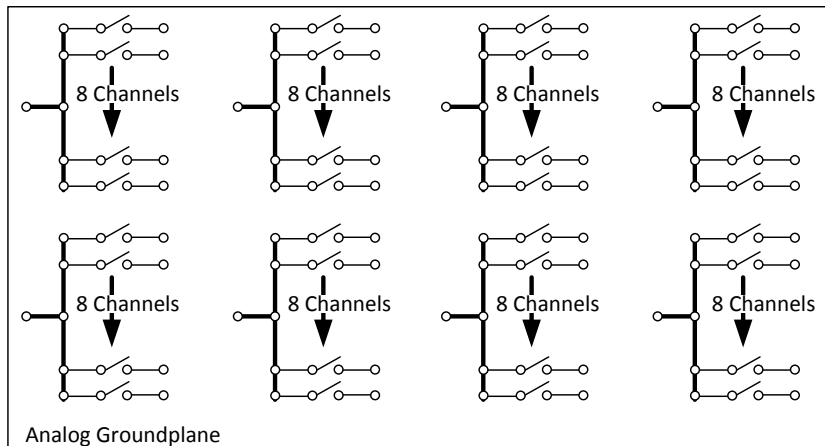
Other Similar Designs



Power Multiplexer

This diagram is for the 3000-01 card. It has 8(1x8) multiplexers specifically designed for power distribution. The designer assumed that a user might want to turn on more than one DUT at a time, so the input side of the multiplexer is designed with thicker wiring rated for 15 Amps and the output side is rated for 5 Amps. This design prevents the test engineer from unwittingly turning on multiple DUT's and overheating the input side of the multiplexer. It should also be noted that this card is designed using discrete wiring rather than by using heavy PC traces as many competitors do. This method is more costly to build, but was done intentionally for two specific reasons:

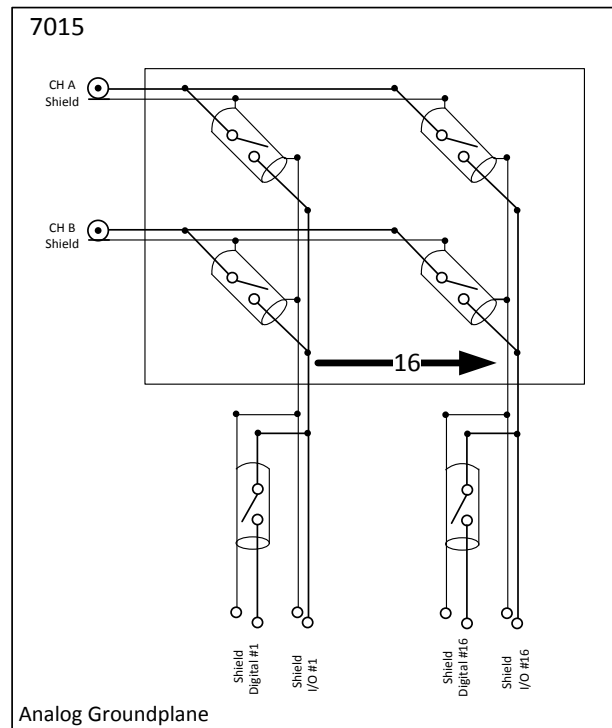
- 1) Boards which have been subject to an overcurrent condition can be repaired by replacing a wire rather than having to replace an overheated PC board. Since the purpose of an ATE is to test products with potential defects, this event is more likely than not, over the ATE's lifetime.
- 2) The discrete wiring construction allows Giga-tronics_{ASCOR} to easily re-task the board by creating a special wiring diagram. Need a card with 4(1x16) multiplexers? Simple, add a few jumpers to the card below.



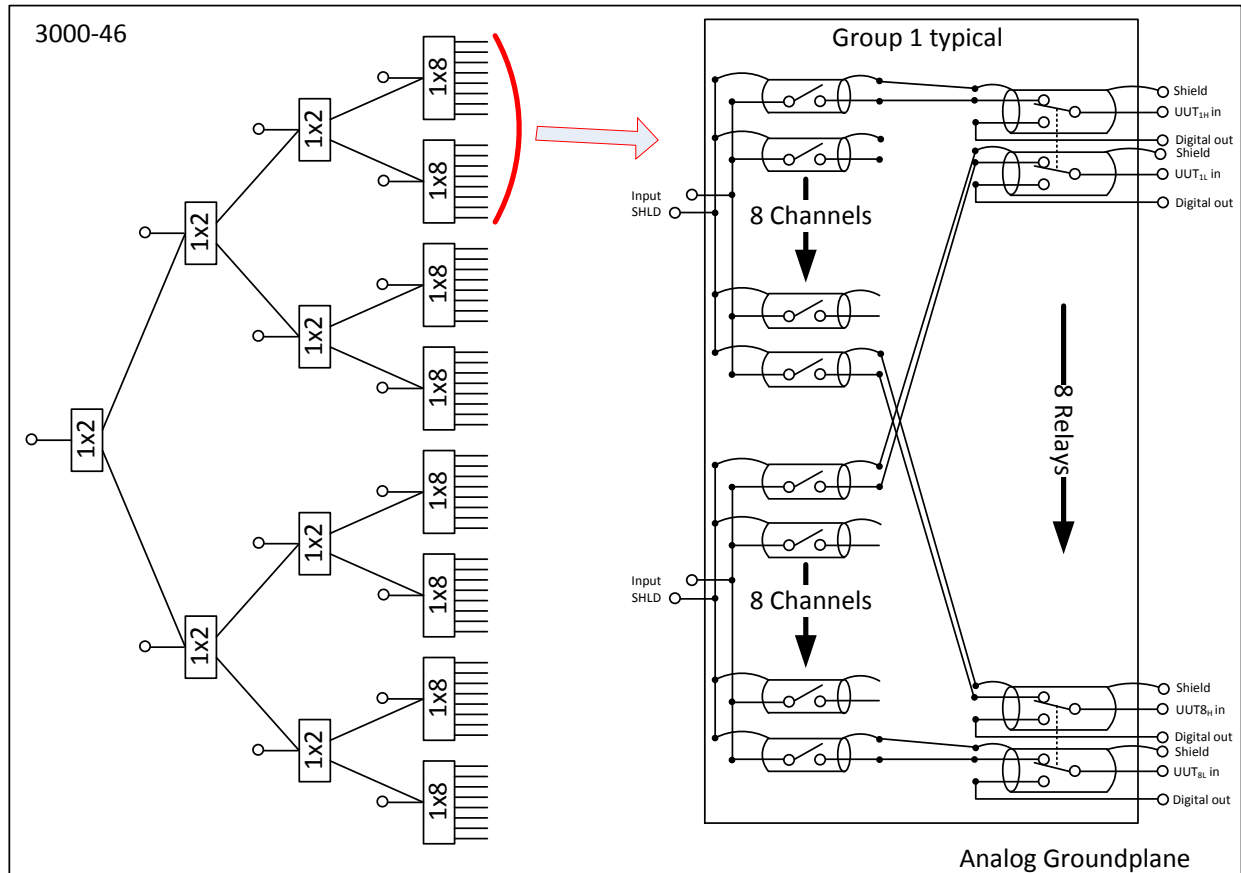
Digital/Analog Mixed Signal Testing

One common theme in the component testing world is to connect the DUT's I/O pins to either digital testing resources for high speed digital testing, or to be connected to analog test instruments to support parametric testing of these same pins (i.e. correct voltage levels, and current source capacity, etc). The challenge in implementing such a switch is to have a high bandwidth path for the digital resources, and a lower bandwidth path for the analog testing resources. Giga-tronics_{ASCOR} has created several solutions to this problem as shown below:

The 7015 PXI card has a (2x16) matrix allowing 2 test resources to connect to any of 16 DUT pins. The interesting aspect of this design is that an additional relay has been added to the incoming DUT pin to provide a high bandwidth connection to the digital resource, leaving only a minimal stub on the line from the connection to two relays in the matrix. Since this card has coaxial connectors on the front to connect to the instruments, the matrix can easily be expanded using coaxial Tee connectors on the front panel.

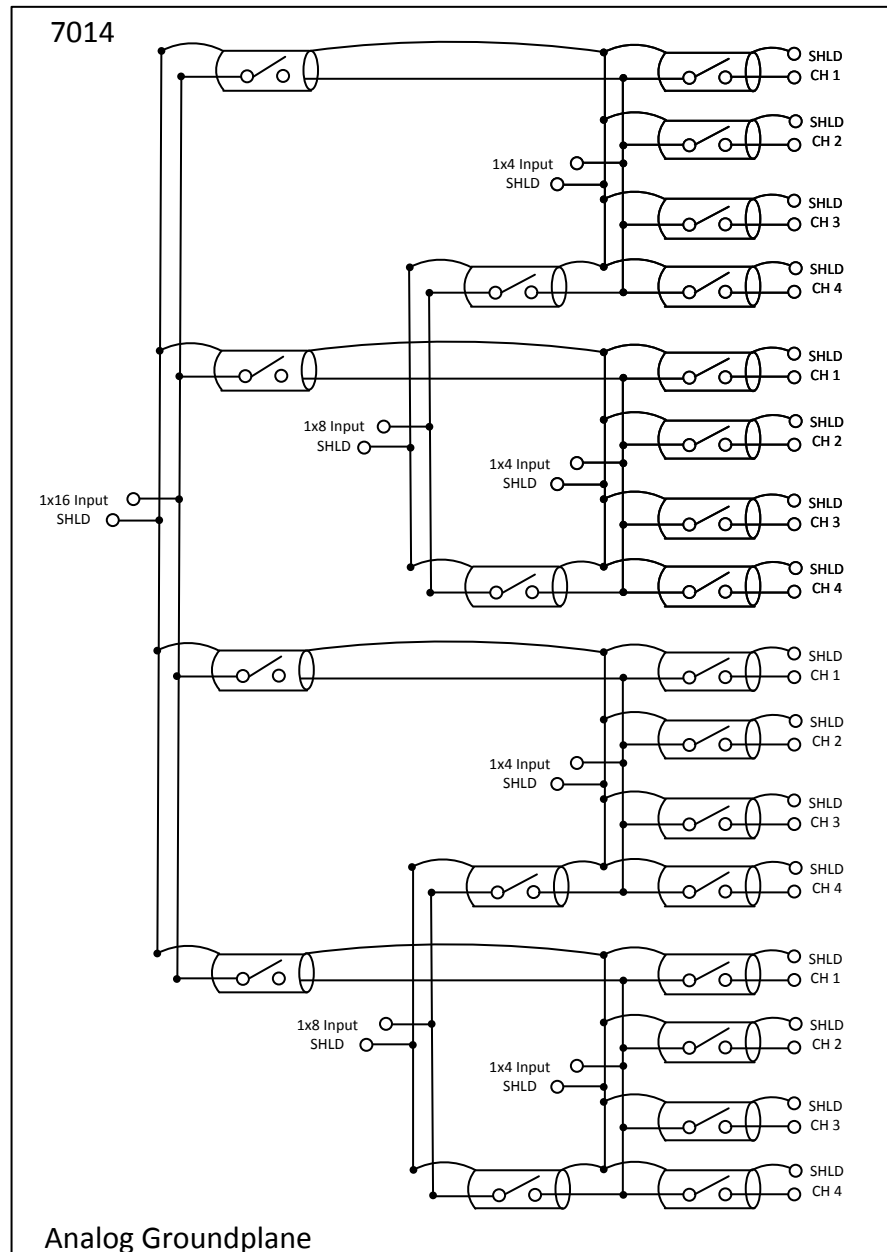


The 3000-46 card is similar to the example above, but because the 3000 series VXI platform is so much larger, the card is much more complex. Like the 7015 card above, the design begins with a universal DUT pin which enters the card, and a decision is made at the first DPDT relay as to whether the signal will be turned around using a high bandwidth shielded signal path to a digital resource, or if the signal will continue into the multiplexer tree where it can be connected to a variety of other instrument connection points. The signals are switched in pairs using DPDT relays since this card was designed to accommodate differential signals.

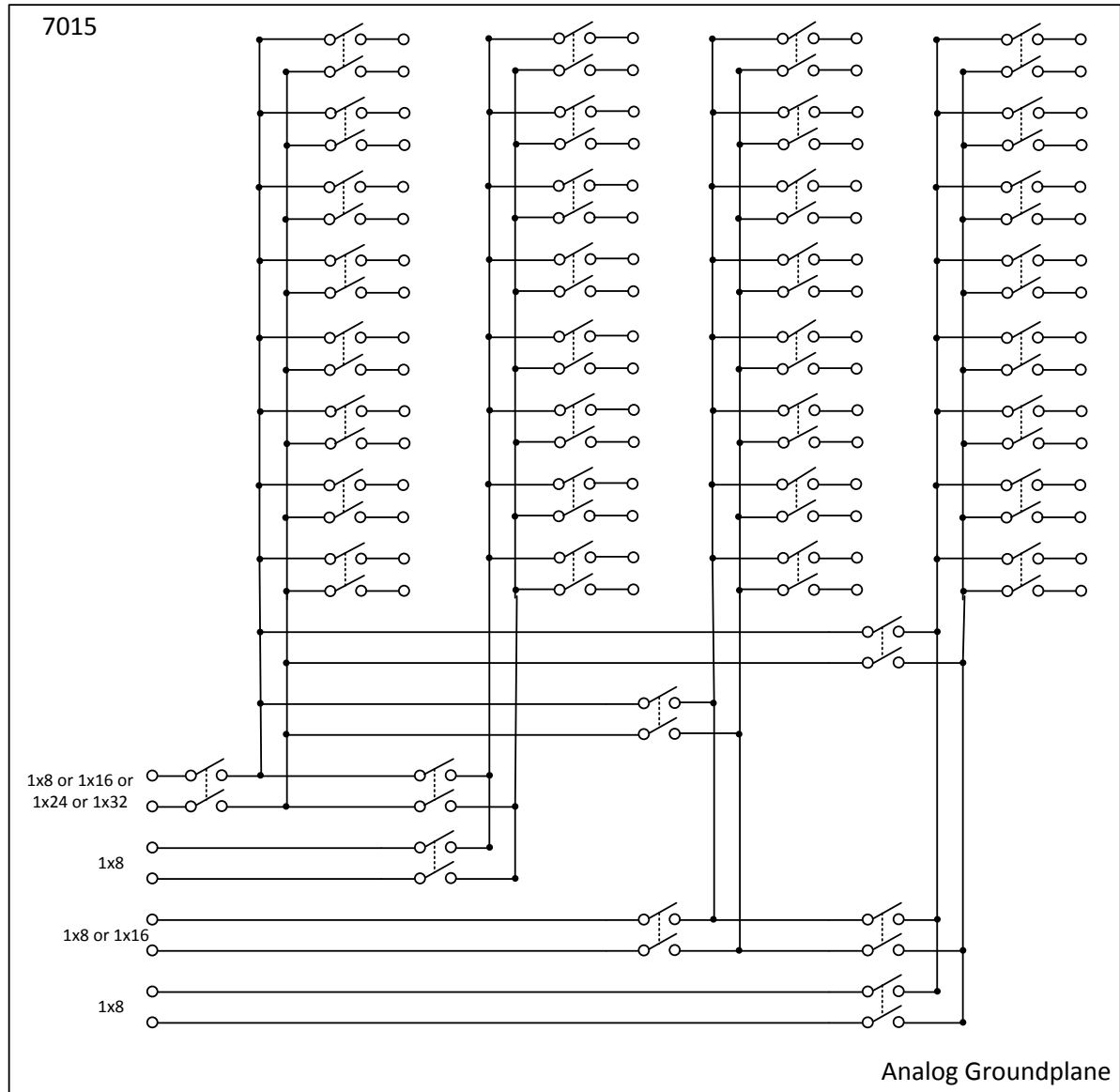


Other Types of Multiplexers

The 7014 PXI card provides a very flexible multiplexer design for a general purpose switching application. Assuming all of the pins are brought to the test interface, the test Engineer can decide what size elements to use depending on the connection points he selects. In this way, the card can behave as 4(1x4)s for one test program, but it can also behave as a (1x16) in another test program. Simple and flexible.



The 7015 PXI card provides similar functionality in an unshielded version. Shielded Relays are significantly more expensive than their unshielded counterparts. Giga-tronics_{ASCOR} offers most of its products in both versions to allow customers to select the price-performance trade-off that best fits their application. As in the previous example, this card can be implemented in different ways, simply by selecting the appropriate connection point.



Summary

So, if you've read all this way and are still with me, you clearly have a strong interest in switching and are probably about to design your own system. Way back at the beginning of this paper I asked you to remember one thing, which is to consider the switch as part of the cabling system and that it should do as little as possible to interfere with the nice balanced system your DUT had before the switch was introduced.

The other thing I hope you take away from this paper is the fact that switching is not so simple and that there are a lot of ways to go wrong. There are also a lot of ways to be creative. That's the real advantage of working with the experts. Once we have a clear understanding of what you are trying to accomplish, we can either steer you to the right product, or modify one of our standard products so that it fits your application better.

So, give us a call. We would be happy to help, at whatever level you feel comfortable with. We can do as little as answer questions about our products, or as much as look at your requirements and design a system for you. It's all up to you. I hope this little paper has given you some ideas, or maybe raised a few questions you need to research further. The bottom line is we're here to help!

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